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ABSTRACT

ADD A DIMENSION TO YOUR ANALYSIS OF THE HELICOPTER LOW AIRSPEED ENVIRONMENT

by 1994

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We have long strived to better define the low airspeed relative wind limits of the helicopter and also to define the helicopter performance in a 3-dimensional (3-D) format. These concepts were first presented in an AHS paper in 1977 (77.33-63) also published as NAVAIRTESTCEN Technical Memorandum TM 77-2 RW of 29 April 1977. Recent analysis of the low airspeed environment for purposes of defining deficiencies and evaluating an Unanticipated Right Yaw (URY) or Loss of Tail Rotor Effectiveness (LTE) problem have developed a new method of reducing and presenting critical azimuth test data. A new method of reducing test data was presented to the Society of Flight Test Engineers in a 1992 paper and involved the automatic handling of test data along with including the oscillatory component of the trim point. In our opinion, presentation formats were more logical than the classical methods of presentation of critical azimuth data, but they were still presented in a 2-dimensional (2-D) format. Dispersion data on the plot gave indications of the third dimension of workload as has been presented by the Army in their reports, but still on a 2-D plot. The location of interference effects could be determined by looking at six or seven 2-D plots of the type presented in the prior paper.

This paper addresses the presentation of critical azimuth test data in a 3-D format which shows on one plot, not only the third dimension, but provides the capability to visualize areas where there are interference effects. A 3-D performance plot for the pilot, used in conjunction with a low airspeed indicator in the cockpit to locate himself on the surface, could provide pilots with the capability to utilize their helicopter more efficiently by optimizing performance, or such other parameters as flying qualities, vibration, or minimize structural loads. Data presentation in both topographic and 3-D surface plot format is discussed, matching the 3-D surface plot envisioned in the prior papers. Benefits of presenting test data in this format are that the interference effects of main-to-tail rotor (advancing and retreating blade tip vortices), tail-to-main rotor, and tail rotor vortex ring state are all clearly evident in the data plots as well as are other aerodynamic and dynamic phenomena. In addition, this approach provides an easy to use capability to provide quantitative test data for the low airspeed environment which correlates to pilots qualitative handling qualities ratings (HQR). The method also allows analysis of effects for which the pilot did not provide qualitative comments. This method provides a concise definition of the low airspeed environment for baseline definition of the airframe so that the interference effects noted above can be included in the development of a simulator.

Both 3-D and topographic plots are covered in the disciplines of performance, flying qualities, vibration, correlation to HQR, and interference effects for several different helicopters, notably the H-2, H-3, and H-60. The addition of a fourth dimension, color, allows visualization and concise definition and presentation of flight limiting conditions.

PARAMETERS MEASURED

Table 1 lists the control, performance, and derived parameters reported in this paper. They are from test programs on the H-2, H-3, and various H-60 airframes. Both steady and oscillatory data were generated for each of the parameters and definitions for each are enumerated in table 1. This paper focuses on data reduction and presentation methods and can be used on any prior test data.

BACKGROUND

In the mid 80's, a series of three accidents occurred involving a Navy ASW helicopter (the SH-2F), in which heading control was lost and the aircraft spun to the right. This led to a survey of fleet pilots to determine if others had similar heading control problems. The survey revealed that over 40 fleet pilots had lost some measure of heading control and several had done 3 to 4 complete 360 deg revolutions before recovering control of the aircraft. The cause of the first accident could not be exactly determined because the helicopter was lost at sea. However, the flight conditions of relative wind for the first and second accident fit the window for vortex

Enclosure (1)

TO WHOM IT MAY CONCERN:

Here is a copy of Professional Papers written by various people here at the Naval Air Warfare Center Aircraft Division. It was requested that a copy of each of the professional papers be sent to DTIC for retention.

If you have any questions, please contact Dorothy Reppel, 326-1709 or (301) 826-1709.

P.S. All the enclosed papers have been cleared for public release.

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ring state (reference 1, figure 13) applied to the tail rotor. In the third accident the tail rotor drive and control systems were found to be in perfect working order but the flight conditions did not fit the vortex ring state window. A review of all of the prior NAVAIRTESTCEN historical test data for this aircraft out of various references (examples in figures 1 and 2) showed that no problem should exist within the normal operating flight envelope and, further, no problems had been encountered before during any of the test phases over a period of about 30 yr. Although the test data indicated that the Fleet should not have a problem, a series of accidents/incidents proved otherwise. Reference 1 contains a discussion of the analysis prior to conducting tests at NAVAIRWARCENACDIV Patuxent River (NAWCAD Pax River).

Army experience with their OH-58 scout helicopter in the late 70's was further researched in order to find probable causes for the accidents. Research into this problem area showed that the U.S. Army had encountered a similar series of problems with their scout aircraft, and had tasked the manufacturer to conduct a test program to investigate it. The Army test program included modifying the tail rotor, adding a yaw SCAS, and determining pilot recovery techniques. The resulting recovery techniques worked for the Army aircraft, not only for the modified configurations, but for the old baseline aircraft configuration as well, so that aircraft modification was not necessarily needed. Navy Fleet training was implemented based on the Army information. The resultant Army training tape, was shown to the Navy squadrons and no more LTE/URY incidents occurred.

THE NEED FOR A NEW METHOD

The lack of useful low airspeed test data on the Navy airframe led to efforts to modify critical azimuth test data reduction and presentation methods. A test effort on a different airframe to try to quantify a flying qualities heading control deficiency of high pilot workload (HQR-5 on the Cooper-Harper scale) utilized statistical analysis methods combined with a modified presentation format yielded an extremely useful new method. Use of this method, described in reference 1, allows the test engineer and pilot to see the changes in the controls and responses of the helicopter as azimuth is varied and therefore the dynamic nature of the test points is reflected in a wider scatter band of the data presentation. This presentation format parallels Army presentation methods (as presented in reference 3, figure 79) and is shown in figure 3. This data presentation method had not been used in previous NAVAIRTESTCEN helicopter flying qualities reports. In fact, tail rotor interference areas defined in the Army and other literature (reference 4) from such things as rotor tip vortices (advancing and retreating blades) and vortex ring state (references 2 and 4) can be seen in the appropriate areas of the test data using the reference 1 method as shown in figure 4. Critical azimuth test data reduction can be enhanced by utilizing statistical methods, spread sheets, and graphics programs. The method defined in reference 1 was recommended as a new standard for reduction/presentation of helicopter critical azimuth test data in order to see aerodynamic interference effects. Efforts over the last 2 yr since publication of reference 1 has shown that loading the test data into a 3-D gridding and presentation program such as "Surfer" (TM Golden Software, Inc., P.O. Box 281, Golden Colorado, 80402: V-4 c 1990) allows better visualization of aerodynamic effects, separation of steady state and dynamic effects, and reduction of the number of data plots needed to present information.

NAWCAD PAX RIVER LOW SPEED FQ&P TEST METHOD AND DATA REDUCTION

Testing is done at NAWCAD Pax River to determine the helicopters ability to hover in the wind and do a mission such as hold position and recover someone from the water. This piloting task is one of position keeping (x and y position or position error, altitude, and heading) in the wind environment. It would be ideal to be able to control the environment sufficient to do our critical azimuth testing from 0 to 360 deg and 0 to 35 kt *but that is not feasible.* We do testing by substituting a pace vehicle as a reference point in whatever the low wind environment is on the test day to establish the desired test point. The piloting task in this case becomes one of tracking the pace vehicle (parallel path, speed error (or RELATIVE position error), altitude, and heading). There are some who say that these are different tasks and would have different results, and the possibility exists that the environment might also be slightly different due to wind speed variability and altitude gradient. Suffice it to say though, that all of the test data shown herein were generated using the paced method and stabilizing at each test point for approximately 10 to 15 sec. Procedures for use of the pace truck are included in enclosure (1).

In order to provide maximum, minimum, and average data information for aircraft state data for each

parameter during a 10 to 15 sec, stabilized critical azimuth test point, statistical methods were run on 16 parameters at the Real-Time Telemetry Processing Facility including control positions, attitudes, rates, Doppler ground velocities, and tail rotor blade angle. The data included a printout of the parameters during the playback, plus an ASCI II data file stored on a 5 1/4 in. high-density floppy disk which is called up into a spreadsheet program on the personal computer.

NAWCAD Pax River has used several critical azimuth data presentation formats in the past, such as, the 0 to 360 deg XY plot or polar presentations of figures 1 or 2. Plotting critical azimuth in a -180 to 180 deg format (figure 4) has the advantage of placing winds on the nose in the middle of the graph. Left relative winds are on the left, right relative winds are on the right and the discontinuities due to weathercock stability are at the right and left margins of the graph. The format shown in figure 4 is plotted with an added area connecting the max and min points as an indication of workload. Data can also be plotted as + and - from the average by making the calculation of "max" minus "min" divided by two (equivalent to vibratory 1/2 amplitude) and plotted as shown in figures 5 and 6. This was the data presentation format used to support the handling qualities deficiency discussed in a subsequent paragraph.

The maximum, minimum, and average critical azimuth data can be presented as an area plot as shown in figure 4. Data shown in this format has the standard "average" data plotted in the center which compares to all the existing test data. The area plot, however, provides insight into how hard the pilot is working at the controls, how well the aircraft is responding in attitudes, rates, and accelerations. A square root of the sum of the squares on the Doppler horizontal and drift velocities (VH and VD) gives the resultant groundspeed (VR) as a check on how well the test point was flown as shown in figure 7.

Use of the above method and presentation format allowed NAWCAD Pax River engineers to support the pilot's qualitative poor HQR (HQR-5) associated with critical azimuth tests with supportive quantitative test data presentations. This data supported the pilot's assignment of an HQR value during the test. As an example, the pilot, looked at one page of data after the flight (figure 5) and commented that the HQR values at -45 deg should have also been a HQR-5 (trying to second-guess his in-flight assignment of HQR after looking at part of the data). Subsequent discussion indicated that in the areas listed as HQR-5 the pilot was active, not only with pedals (figure 5), but with lateral and collective controls as well (figure 6). However, at the -45 deg azimuth test point he was only active on the pedals, confirming his initial in-flight assignment of a HQR-4.

Reference 1 cited advantages of the new method of presentation of critical azimuth test data. They included capability to locate and "see" in the test data plot the effects from disturbances such as the interference effect to the tail rotor from an advancing main rotor tip vortex at relative winds of 20 kt from +60 and +90 deg as an increase of pedal displacement to maintain the stabilized test point. This interference can also be seen in the normalized heading deviation plot of figure 5 as well. Effects can also be seen from the retreating blade vortices, and vortex ring state area as well, as shown in figure 5.

When the test data generated in the method of reference 1 was inserted into a 3-D gridding program the interference effects described above became quite obvious on the plots.

POLAR VERSUS CARTESIAN COORDINATES

For the pilot and test engineers conducting the test the standard format is Polar Coordinates. 30 kt wind from 330 deg is specifically how the test point is set up. Use of the 3-D gridding program, however, requires input of data in Cartesian Coordinates and viewing the plots in this format requires the viewer to translate back to Polar to identify his test point. This mental translation is difficult at first, as is identifying the orientation of the plot (e.g., nose forward) on the surface plot, since different orientations are selected to best show the contour surface. One of the problems that can occur is that once oriented nose forward then left and right are reversed. Figures 8 and 9 show this condition. Also, selection of the Z scale is important since not all parameters are intuitively obvious. The topographic plots are always plotted with nose forward (0 deg relative) at the top of the page. Once these mental translations become familiar, use of the surface plot and topographic maps become extremely powerful tools for presentation of test data and showing nonlinearities and interference effects. In addition, more data can be shown on a single plot. For example, to show the steady state critical azimuth data for a 360 deg azimuth, 35 kt test sequence would require six figures, one each at 5, 10, 15, 20, 25, 30, and 35 kt. This same data can be shown on two

figures; a surface plot (figure 10) from which trend information and nonlinearities can be identified, and its corresponding topographic plot (figure 11) from which accurate data numbers can be read. Both plots shown represent engine torque.

STEADY AND OSCILLATORY INFORMATION

NAWCAD Pax River has always presented the trim points which constitute the average of the test data (steady) during a given stabilized test point. Recently (reference 1) we have adopted the presentation format used by the Army, which gives indication of the oscillatory component in the data. Reference 1 proposed that the steady state and oscillatory data be handled separately. Figure 12 presents a definition of how these steady and oscillatory data were defined and developed. Table 1 defines the terms used in the rest of this paper for both the steady and oscillatory components of the test data.

CORRELATION WITH HQR DATA

As noted earlier, the first use of the oscillatory component of the stabilized test point was to support a high pilot workload in heading (pedals) at a particular relative wind azimuth. Reduction of these data by a new, fully-automated method, resulted in being able to support the test pilots qualitative comments with quantitative test data. This is reported in reference 1 and an INSURV Yellow Sheet Report. Further analysis and reduction of data from another test effort to include presentation of the test data in 3-D format indicated how powerful this presentation method is. Figure 13 is the pilot comments from the test data card in polar format. Figures 14 and 15 present the pedal cyclic oscillatory component data (pedal workload) in surface plot and topographic format respectively. Figures 16 and 17 present the heading attitude oscillatory component (yaw response) again in surface and topographic format. Figure 18 overlays the pilots comments in polar with the topographic map (cartesian and same scale) and shows that indeed the pilot comments are supported by the test data. Figure 19 does the same for roll attitude (roll response). This same approach can be used in all the other axes of control and response.

INTERFERENCE EFFECTS

Figure 20 shows a surface plot for the HH-60J yaw rate parameter. In this plot, the interference effects of advancing blade vortex, retreating blade vortex, and the vortex ring state of the tail rotor are clearly evident and labeled. Figure 21 is the corresponding topographic plot. In figure 22, one can detect the interference effect of the advancing blade vortex on the horizontal stabilizer of the SH-2F as noted on the figure.

VIBRATION/STRUCTURAL

In the area of structural and vibration several useful parameters can be explored. The oscillatory component of main rotor torque/tail length becomes the vibratory thrust component of the tail rotor required for confirming design of the torsional mode of the aft pylon and fin (figure 23). The oscillatory component of lateral load factor is lateral vibration. In the SH-2F, this characteristic is shown in figure 24. For purposes of track and balance of the rotor this figure shows that wind is needed from -5 to 0 kt in the longitudinal axis, on the left side, or above 25 kt from any azimuth.

USE OF COLOR

Color is one of the options available in the presentation software and can be used to add another dimension to the presentation of test data. It is most commonly used to accentuate the Z axis items on the surface plot, either showing variation on this axis, or showing limits. On the topographic plots it can identify areas of concern or of limits. On the NATOPS Margin surface and topographic plot, green is shown for areas where the performance margin is conservative and red is used for those areas where it is unconservative.

HELICOPTER PERFORMANCE IN THE LOW-WIND ENVIRONMENT

Helicopter performance, as presented in the Navy NATOPS or Army -10 manuals, is inadequate for the helicopter pilot at low airspeeds. For example, figure 25 defines the sideslip and sideward/rearward limits for the helicopter in question. If you replot this information in terms of lateral and longitudinal velocities you get figure 26. There are no definitions of performance in other than the longitudinal forward axis and hover. It does not make sense to define performance if the pilot cannot fly to the point in question, because he lacks appropriate airspeed indications. A conceptual definition of helicopter performance as a 3-D surface, overlaying the flight limits of sideward/rearward and sideslipped forward flight on the X-Y axis (cartesian coordinates) is shown as figure 27 (reference 5). Note that the shaded

areas constitute the limit of information in the Navy NATOPS manual, and the airspeed indicator is unreliable in the shaded area from zero to about 40 kt. The Naval helicopter pilot flies his vehicle on this surface (the low-speed dome) by the seat of his pants on only outside visual reference or on Doppler indication, which is GROUNDSPEED. Helicopter performance, however is based on the airspeed. The USCG HH-65 has a low airspeed system but no Doppler, but it also does not have power required information defined except in hover and forward flight. One use of a 3-D presentation of data is in the "NATOPS Margin" parameter which has been presented for the shipboard environment in approximately 10 NAWCAD Pax River Dynamic Interface reports. This parameter, shown in figures 8 and 9 (and for another aircraft in figures 28 and 29) represents the margin between actual performance of the helicopter and that indicated for the OGE no-wind hover condition in the NATOPS Manual. If the number is negative, there is an unconservative margin and the pilot needs to add extra margin over that which the NATOPS tells him. Combining the 3-D performance surface with a reliable low/omnidirectional airspeed indicator could provide a capability to optimize use of the helicopter.

SIMULATION

This paper, along with reference 1, proposes modifications to test data reductions and presentation methods for the low airspeed environment. Reference 1 recommends this present analysis and presentation method to indicate and quantify tail rotor vortex ring state, main and tail rotor tip vortex, and other interference effects in order to more fully define problem areas. Use of the new analysis and presentation method on the test data can serve as a basis for defining aerodynamic phenomenon and nonlinearities for use in a simulator to improve the low airspeed models. Reference 1 addresses the requirements for orienting the aircraft characteristics in airspeed to the relative wind and visual earth axis (i.e., groundspeed). By combining 3-D surface plot technology to define low speed performance in the wind axis with proper relation of this axis to the earth axis as indicated in the simulation results of reference 6 noted below, we will have made great strides toward understanding the helicopter nonlinear low airspeed environment. Addition of a low/omnidirectional airspeed system will allow the pilot to make maximum use of his helicopter.

ACKNOWLEDGEMENTS

In my struggle to better understand these frustrating flying machines called helicopters, acknowledgement is made of discussions with LT Dave Green many years ago (circa 1965) in the back room at Flight Test Division, Rotary Wing Branch. During these discussions, he explained to me, then a junior engineer, his concept that low airspeed performance of the helicopter can be defined as a 3-D surface. From these discussions came first a conceptual definition, presented in 1977 in reference 5 as figure 5 and again in 1992 in reference 1 as figure 17. Several speeches followed by CAPT Bill Wirt presenting variations of this figure, and finally this paper, carrying the idea of 3-D surface plots forward to the presentation of actual flight test data in a 3-D format, not only for performance, but for a variety of other parameters as well. My hat is off to all of you pilots who fly and can hover these nonlinear machines but especially to those of you who can also qualitatively evaluate their "weird" disturbances which we as engineers can then learn to quantify.

Patuxent River URY/LTE test results were provided to DTRC to be used in a SH-2F simulation for investigation of the URY/LTE problem/phenomenon. In this significant simulation effort by Dr. David Haas and Kelly McCool, the SH-2F has been shown to spin up to 2.2 revolutions before recovery can be effected, given a delay of 5 sec in application of the pedals needed when the relative wind goes through 180 deg while turning downwind to the right. Results of this simulation were recently presented by Kelly McCool at the AHS Specialist meeting in San Francisco and published in reference 6. This effort is the next step toward having a capability in a manned flight simulator to have pilots experience the loss of heading control that occurs in the real aircraft and be able to train them in proper recovery techniques.

CONCLUSIONS

Navy Fleet training utilizing Army scout helicopter information and recovery techniques has had a positive effect on the Navy's LTE/URY problem.

Review of prior critical azimuth test data on the problem aircraft provided no clues that the URY aerodynamic phenomenon was present.

Use of statistical analysis methods on aircraft state

parameters, combined with a modified presentation method, provides a semi-automated reduction method. This method allows visualization of tail rotor interference areas from advancing and retreating main rotor blade vortices, and vortex ring state.

The method presented in this paper parallels the Army LTE/URY data presentation method.

Helicopter performance should be defined as a 3-D surface to help illustrate performance parameter variations.

Pilots should be provided with low/omnidirectional airspeed systems.

RECOMMENDATIONS

Use the methods defined herein to help improve reduction/presentation of helicopter critical azimuth test data.

Provide low/omnidirectional airspeed systems on all helicopters.

REFERENCES

1. SFTE Paper "Analysis Tools Derived from Investigating Aerodynamic Loss of Tail Rotor Effectiveness (LTE)", by H. G. Kolwey, presented 7 Aug 1991, St. Louis, Missouri.

2. "OH-58 Loss of Tail Rotor Effectiveness", by Capt. David M. Snellen, U.S. Army Aviation Digest, Sep 1984.

3. "Preliminary Airworthiness Evaluation of the OH-58C with 3-Axis Stability Control Augmentation System and improved Tail Rotor System" USAAEFA report 83-15 of Oct 1983.

4. "Tail Rotor Performance in Presence of Main Rotor, Ground, and Winds", by Wayne Wisener and Gary Kohler, Journal of the American Helicopter society, Jul 1974.

5. AHS Paper, "Summary of Helicopter Airframe Testing in the Shipboard Environment", 77.33-63, by Herman G. Kolwey - also published as NAVAIRTESTCEN TM 77-2 RW of 29 Apr 1977.

6. "Analytical Investigation of Flight Conditions Leading to Unanticipated Right Yaw", A paper to be presented to the AHS Aeromechanics Specialists Conference, 19-21 Jan 1994, San Francisco, CA, by Kelly McCool and David Haas.

LOW AIRSPEED CRITICAL AZIMUTH TEST PROCEDURES

1. Van Assignments: Driver, Radios, Computer Operator*

2. Equipment: Fifth Wheel with cable (Cable length to speedometer) and associated support equipment. Computer (portable), Hand-held radio, portable radio pack. Source of wind data (Tower, hand-held anemometer)
*Computer program resolves ambient wind components (True Wind) and desired speed and azimuth (relative wind) desired for the test point with selected runway and direction and computes paced speed for the vehicle and aircraft heading.

3. Complete brief prior to the flight required including discussions of:
   1. Pace Vehicle reaction to an emergency.
   2. Aircraft emergencies.
   3. Lookout responsibilities.

Vary aircraft azimuth with constant pace speed.

Communications:
1. Van to Tower for winds to aircraft for azimuth and speed.
   On-Speed call.
2. Tower to Wan for Wind Data.
3. Aircraft to Van confirm stable on-speed, Data ON, Data OFF, next point. Controls position of pace vehicle.

Two-way communication when crossing at runway intersections.

Data points and buildup techniques and communications are fully discussed.

Aircrew and pilots brief standard aircraft brief to include crew brief (if required).

Van is requested in advance (duty office, or PW). Fifth wheel is installed as is the positioning device (if used). Crew loads up the support equipment. Tower personnel are dropped off at the tower. Van establishes communications with the Tower and proceeds to runway 2/20 (or other in used) and awaits arrival of the aircraft.

On Runway

Pace vehicle secures winds from the tower and calculates the first test data point. Van calls the aircraft to give it aircraft speed and heading information. (If pace speed is to be greater than 20 mph, the aircraft will start transitioning first to match speed with the pace vehicle. If less than 20 mph, they will start together.) As van and aircraft proceed down the runway, azimuth position are given to the aircraft after each data point is completed. Aircraft and van position at end of runway and process is repeated.

Concerns

Aircraft to van spacing. Sufficient space required for emergencies.

Time required in the Hot Pits to refuel for maintaining gross weight.

Wind variability is checked during each run. A time history can be provided by the tower.

Table 1
CONTROL, PERFORMANCE, AND DERIVED PARAMETERS

CONTROL/AXIS				
Axis	Steady		Oscillatory	
	Control	Result	Control	Result
Pitch (B1s)	Long. Cyclic	Pitch Att.	Long. Work Load	Pitch Response
Roll (A1s)	Lat. Cyclic	Roll Att.	Lat. Work Load	Roll Response
Yaw	Dir. Pedals	Heading	Pedl. Work Load	Yaw Response
Vertical (Zw)	Collective	Altitude	Coll. Work Load	Vertical Response

PERFORMANCE		
Parameter	Steady	Oscillatory
Torque (MRQ)	Average Torque	Torque Deviation/Oscill.
Normal Load Factor	Normal Load Factor	Vertical Vibration
Lateral Load Factor	Lateral Load Factor	Lateral Vibration
Doppler Long. Velocity	Average Long. Velocity	Longitudinal Velocity Response (accel.)
Doppler Lateral Velocity	Average Lateral Velocity	Lateral Velocity Response (accel.)

DERIVED PARAMETERS		
Parameter	Steady	Oscillatory
MRQ/Lt (delMRQ/Lt)	"Apparent" TR Thrust	TR Thrust Variation
TRIMPPIT-Pedals	AFCS Effectiveness	
Qtstpoint-Qnatops	NATOPS Power Margin	
Vr (resultant groundspeed)	Groundspeed	Groundspeed Variability (how well trimmed)
Structural		
Strake Pedls-Pedlc	Pedal Pos Difference	Pdl Workload Difference

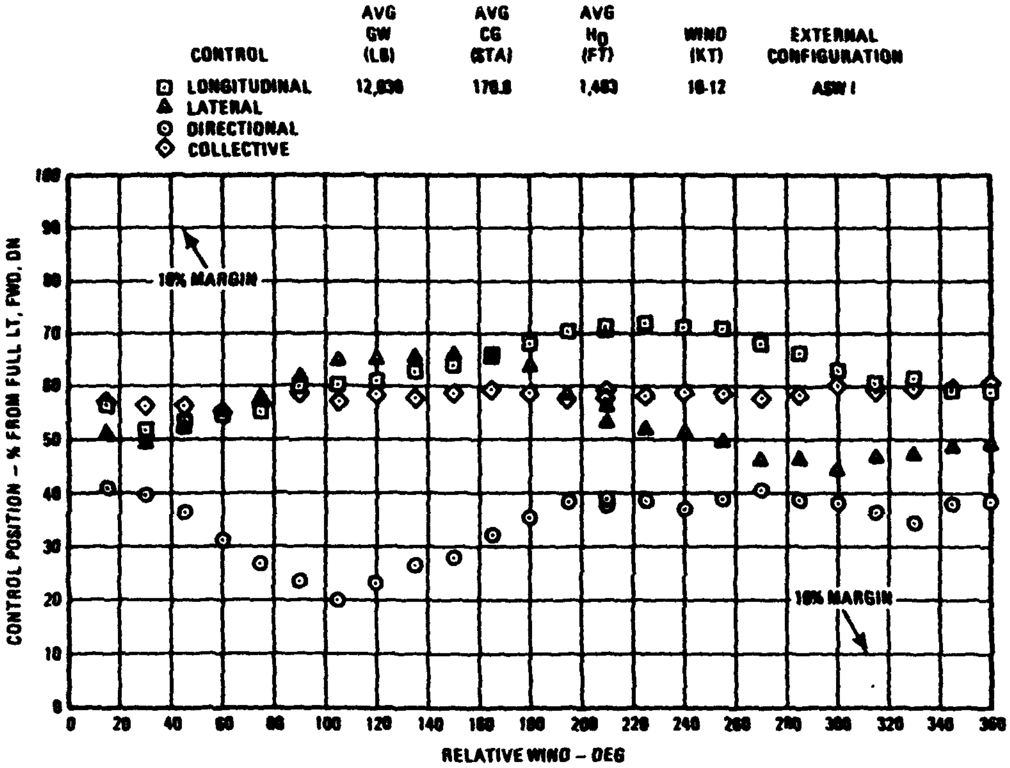


Figure 1
10 KT CRITICAL AZIMUTH

GW = 13,500 lb

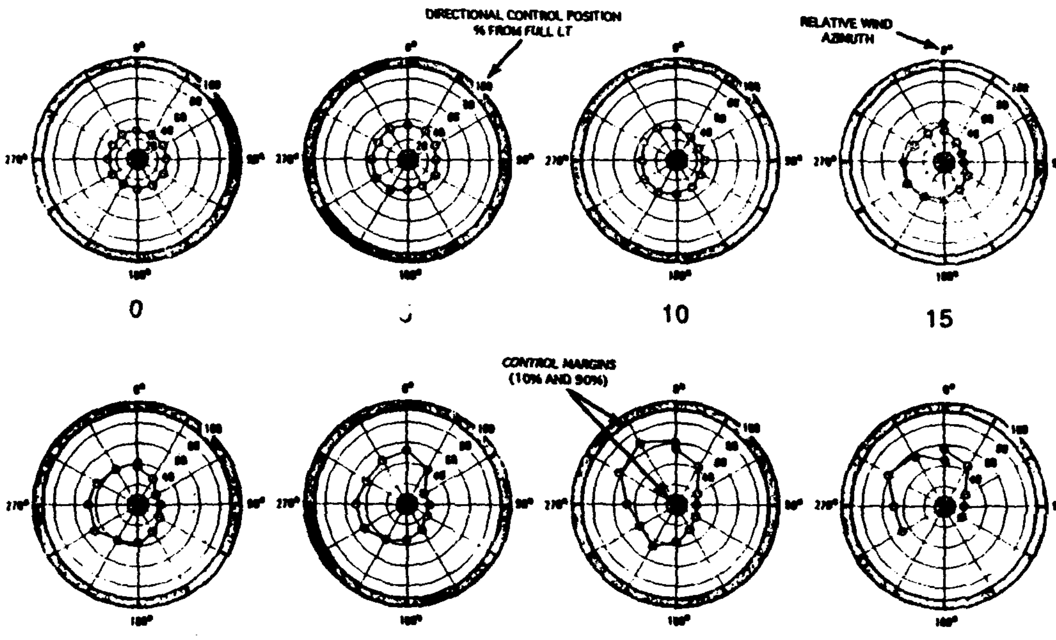


Figure 2
CRITICAL AZIMUTH - PEDAL POSITIONS
0 TO 35 KT RELATIVE WIND

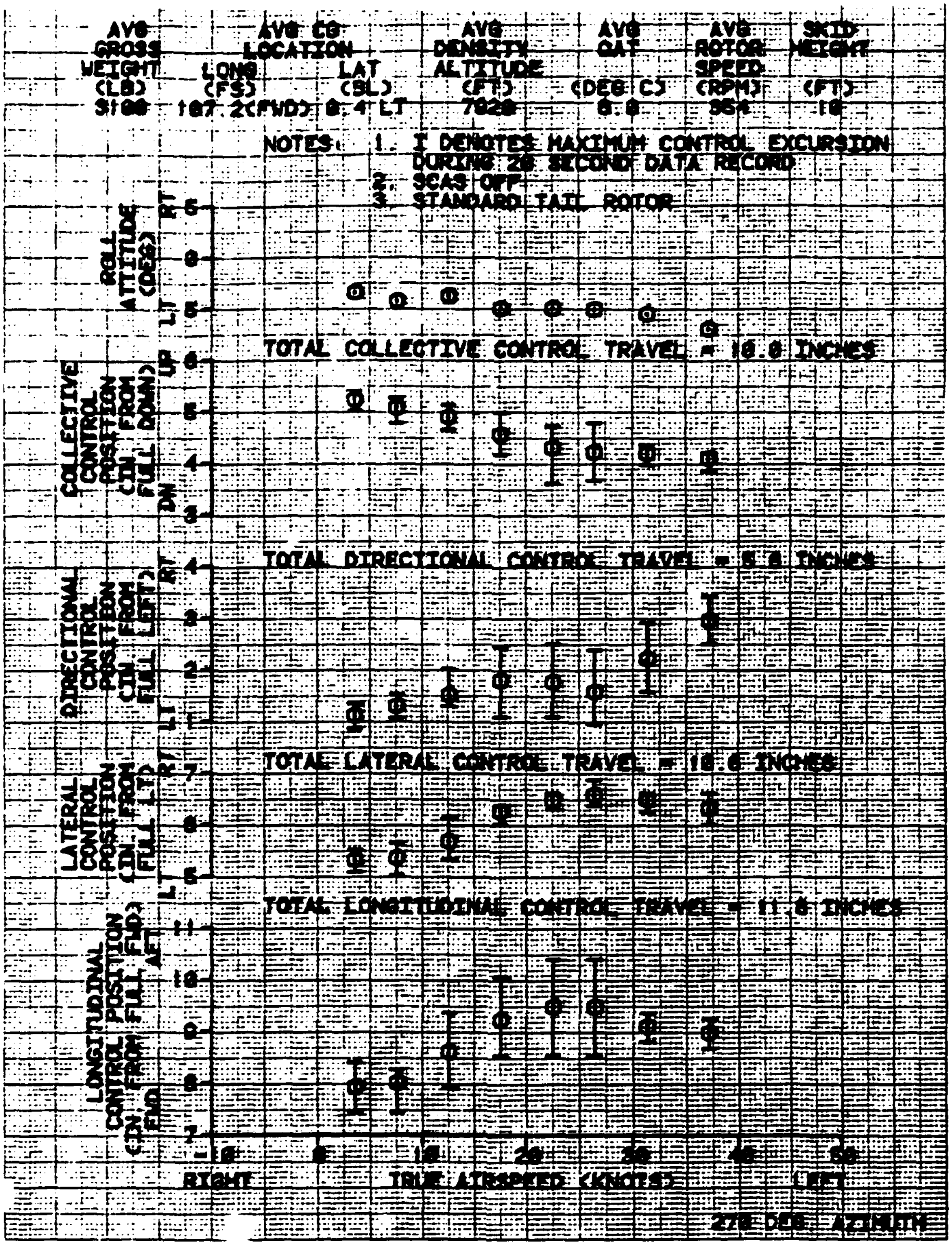
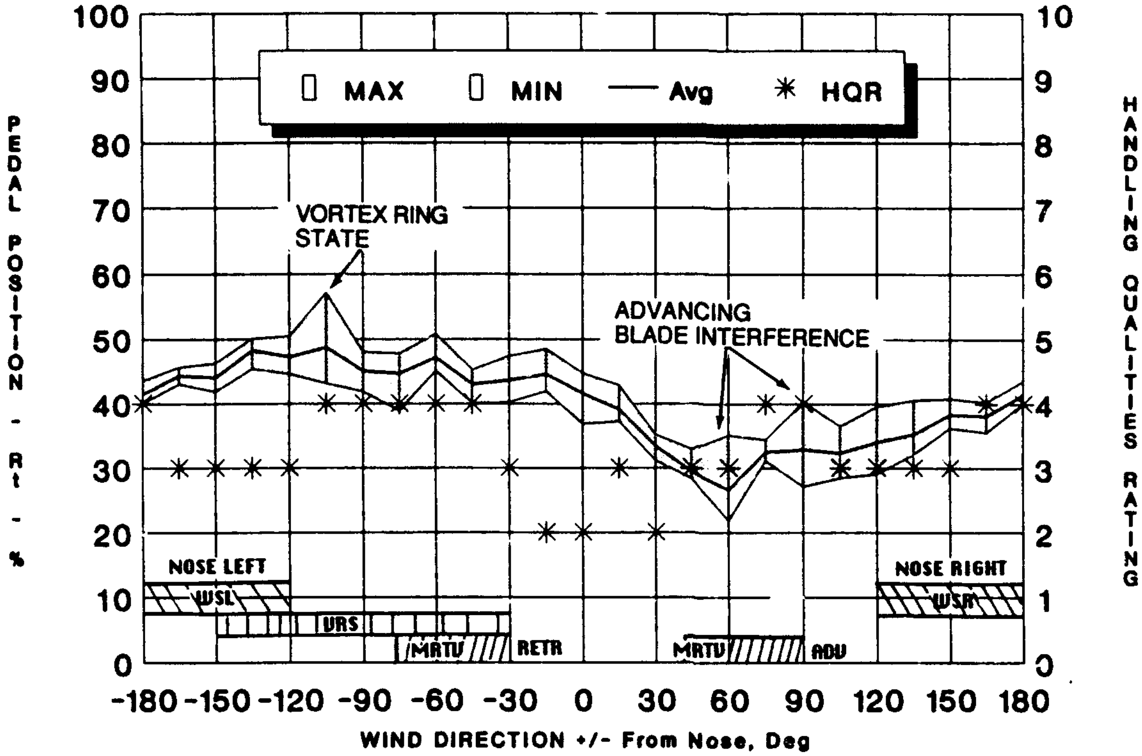
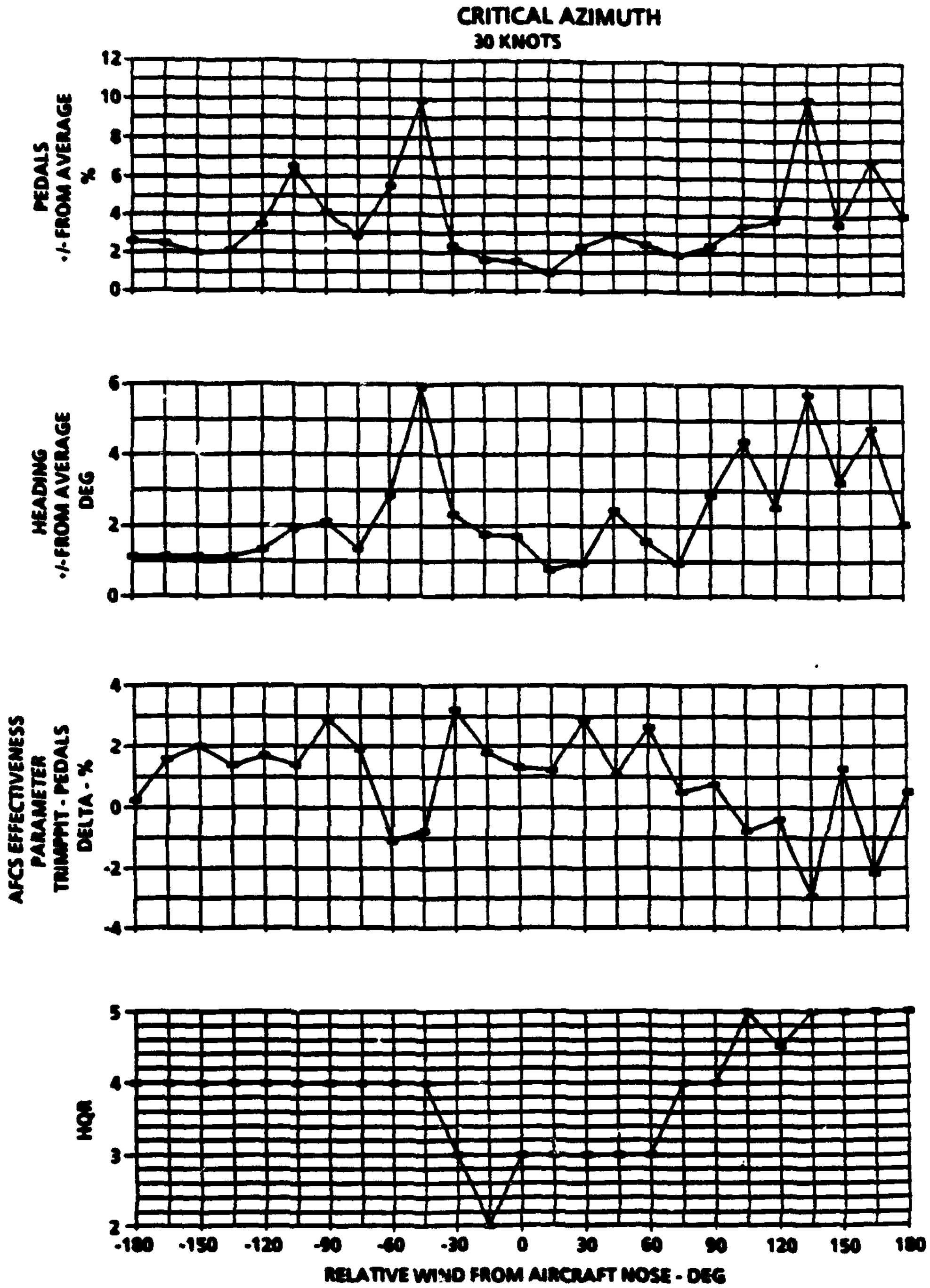


Figure 3
LOW SPEED FLIGHT 270 DEG AZIMUTH
CH-58C USA S/N 68-16850



MRTV = Main Rotor Tip Vortex
VRS = Vortex Ring State
WSL = Weathercock Stability Nose Left
WSR = Weathercock Stability Nose Right

Figure 4
CRITICAL AZIMUTH
20 KT



NOTE: AFCS Effectiveness Parameter = Tail Rotor Impressed Pitch (%) minus Pedal Position (%)

Figure 5
AFCS EFFECTIVENESS PARAMETER AND HANDLING QUALITIES RATING SCALE

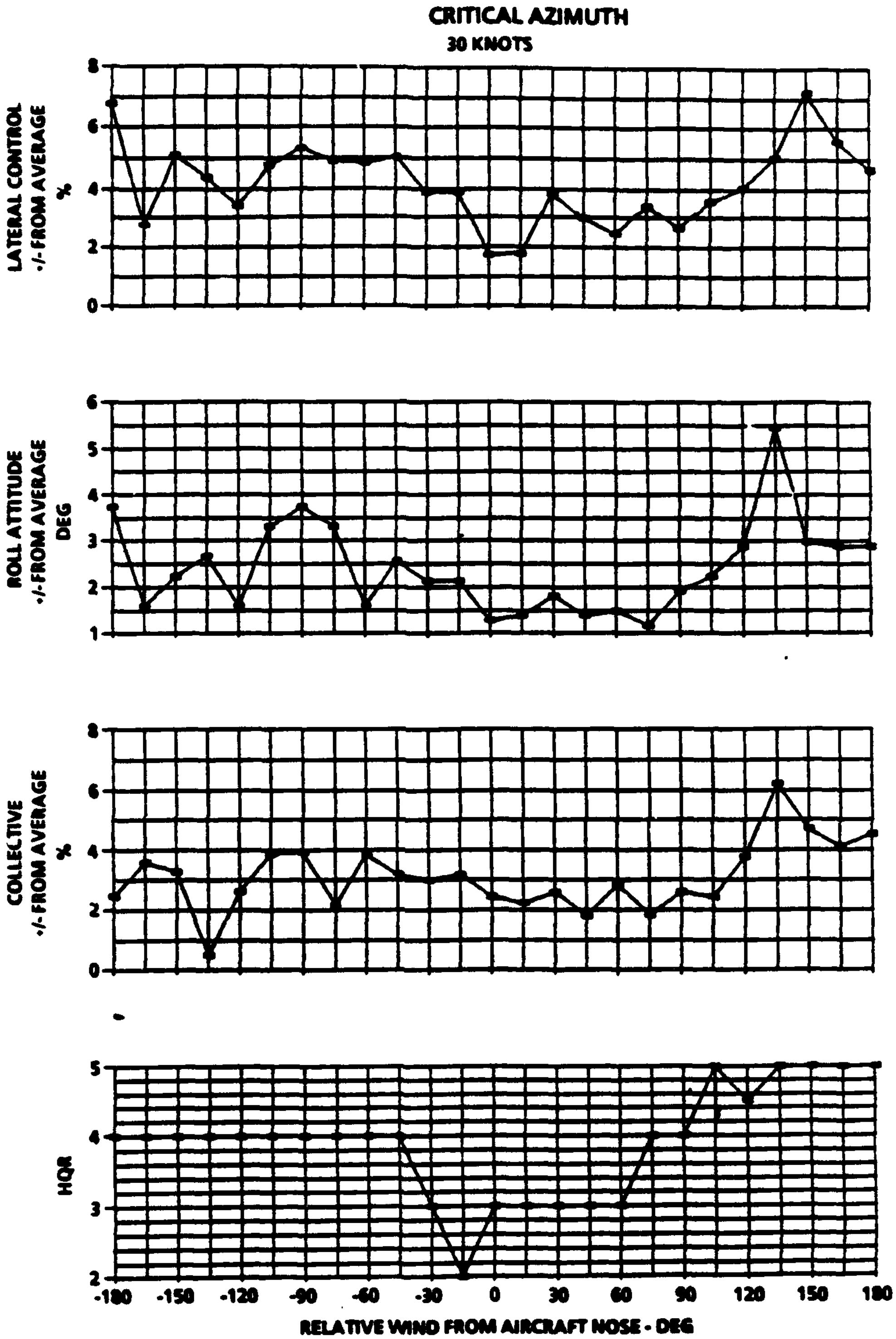


Figure 6
AIRCRAFT STATE AND HANDLING QUALITIES RATING DATA
(Roll and Collective)

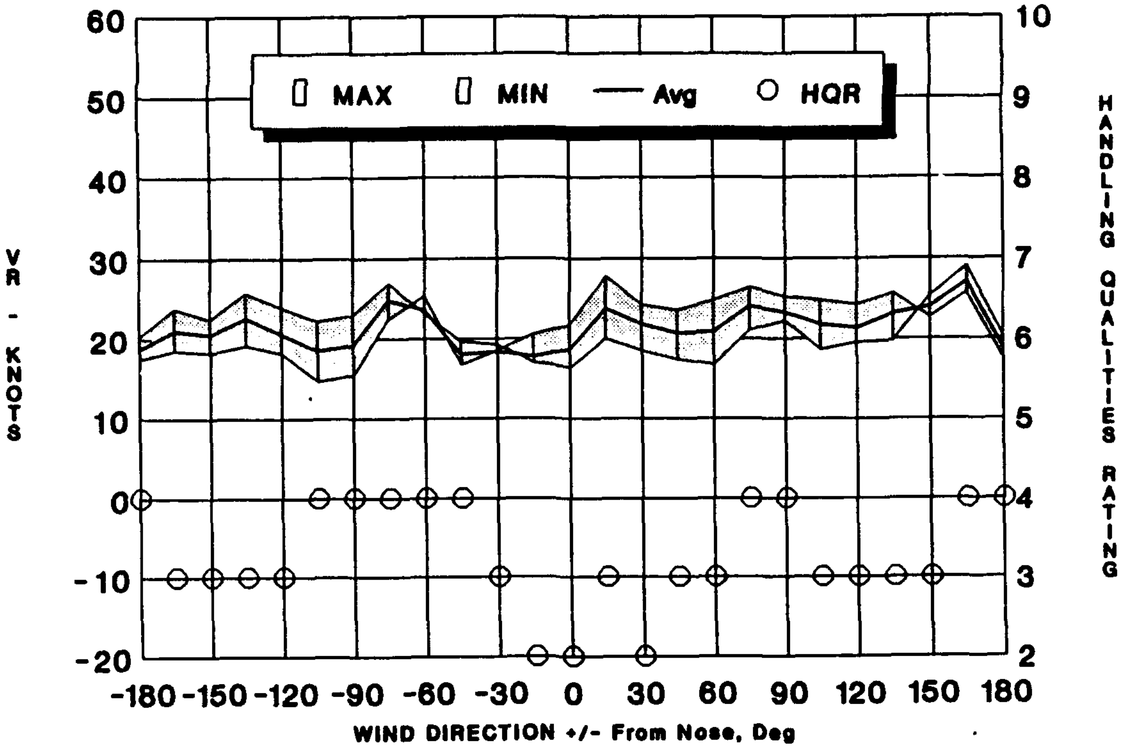


Figure 7
CRITICAL AZIMUTH - 20 KT

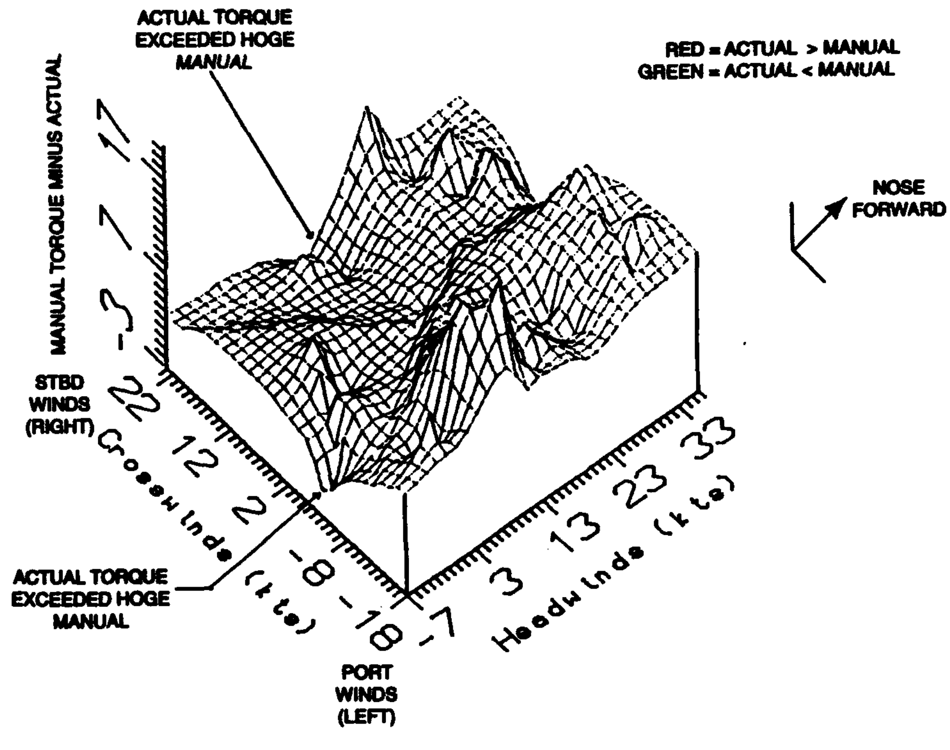


Figure 8
VARIATION OF CH-53E TEST HOVER TORQUE WITH NATOPS HOGE TORQUE PREDICTIONS

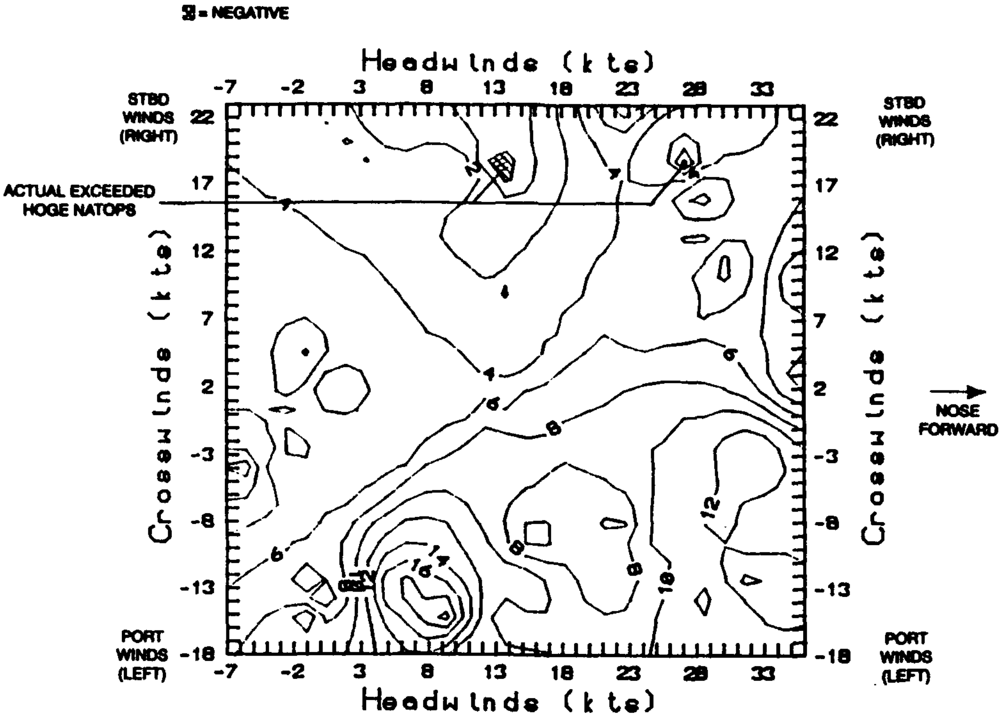


Figure 9
VARIATION OF CH-53E TEST HOVER TORQUE WITH NATOPS HOGE TORQUE PREDICTIONS

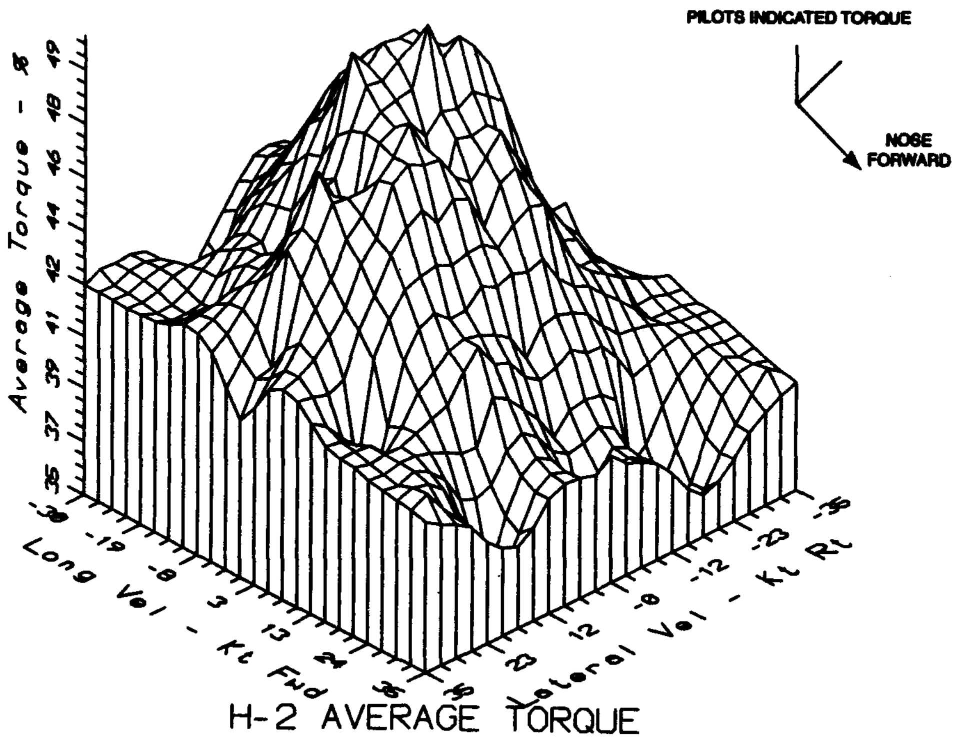


Figure 10
SH-2F AVERAGE TORQUE (SURFACE)

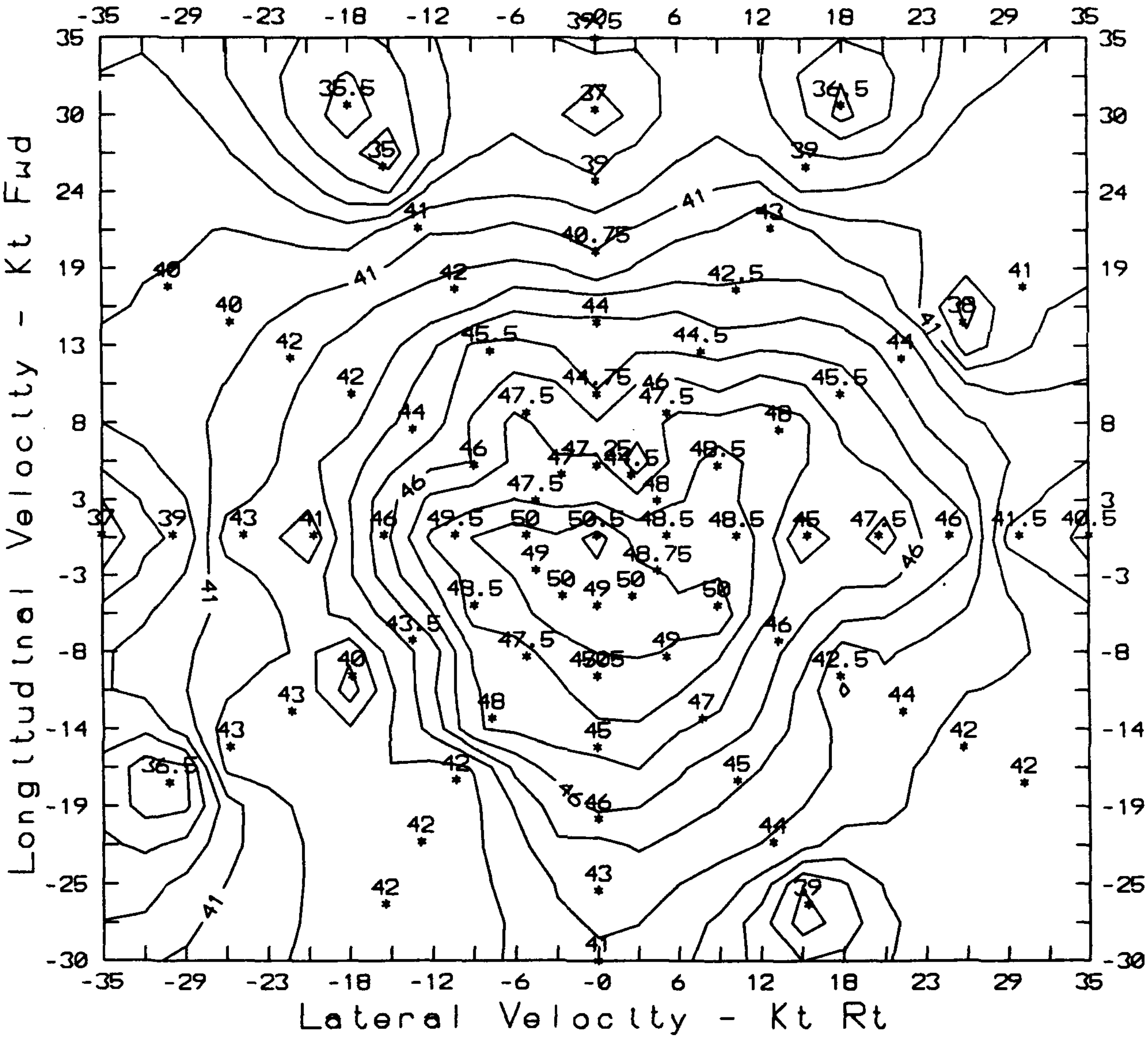
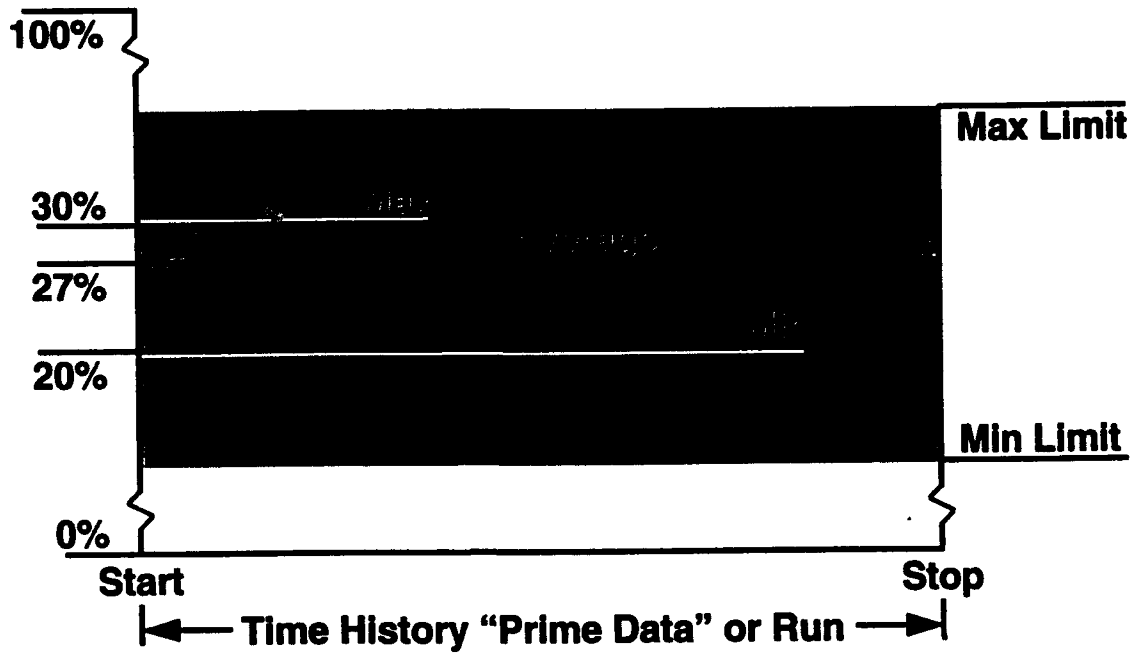


Figure 11
H-2 AVERAGE ENGINE TORQUE
(TOPOGRAPHIC)

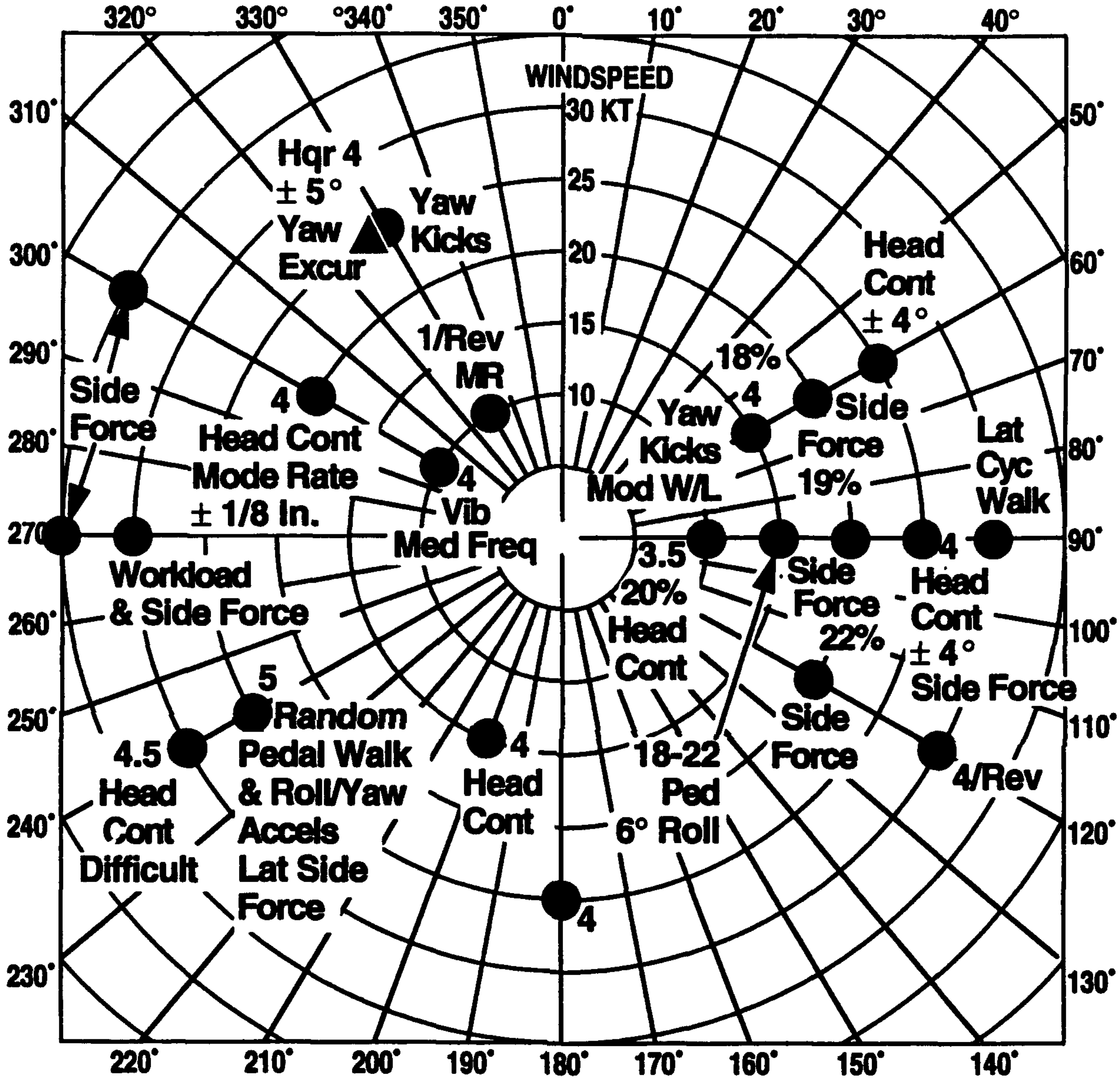
Analysis Program Reduces This Time History...



... to This Tabulation...

Run#	Max	Min	Avg	Exceed Limit
8	30	20	27	0

Figure 12
TIME HISTORY



▲ T700/SH-2F (= SH-2G)
DI Feasibility

● SH-2F 12,800/173

Figure 13
HQR RATINGS (POLAR)

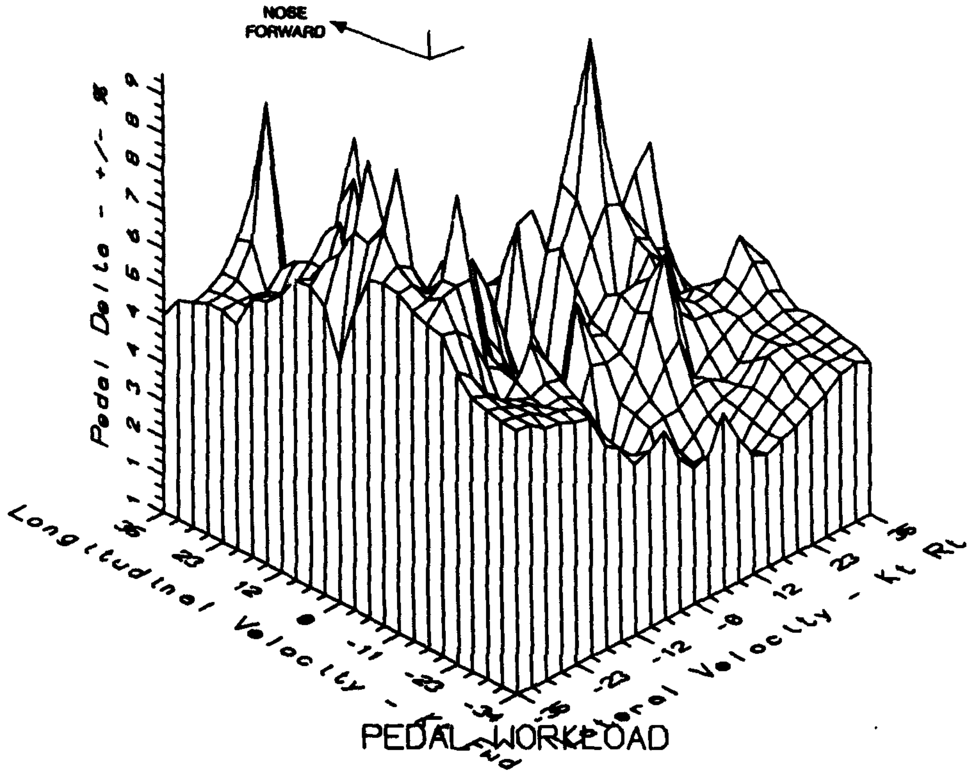


Figure 14
DELTA PEDALS (SURFACE)

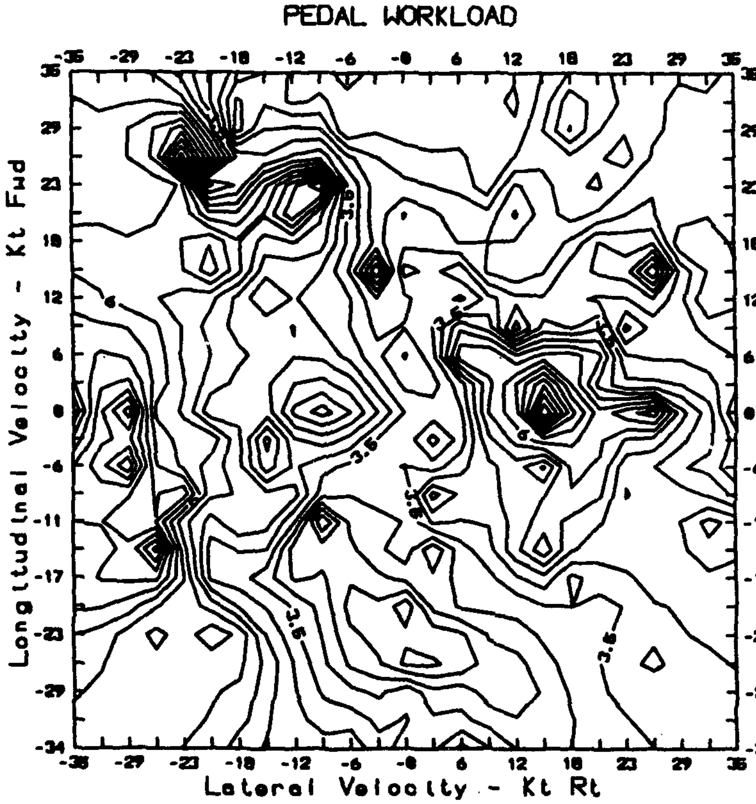


Figure 15
DELTA PEDALS (TOPOGRAPHIC)

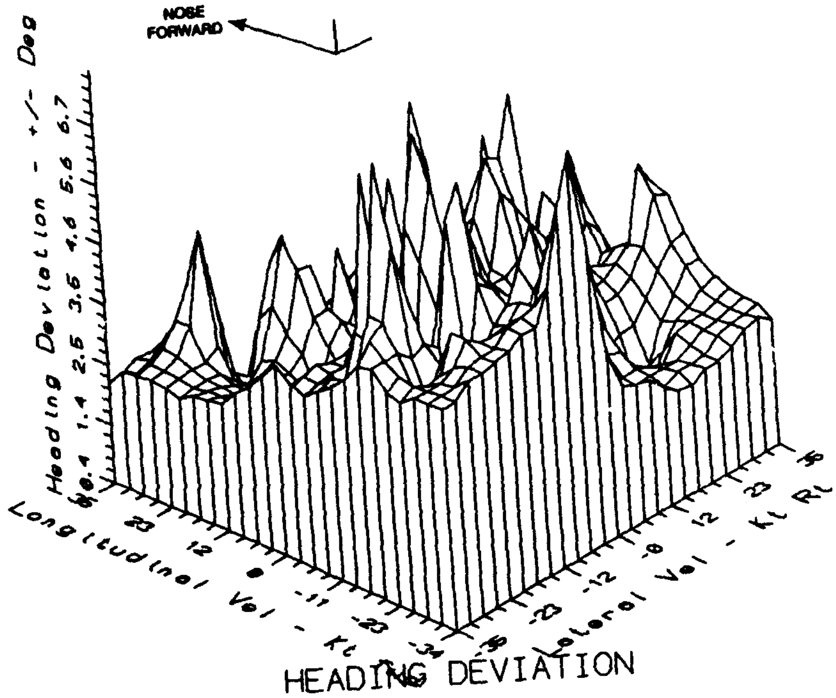


Figure 16
HEADING DEVIATION (SURFACE)

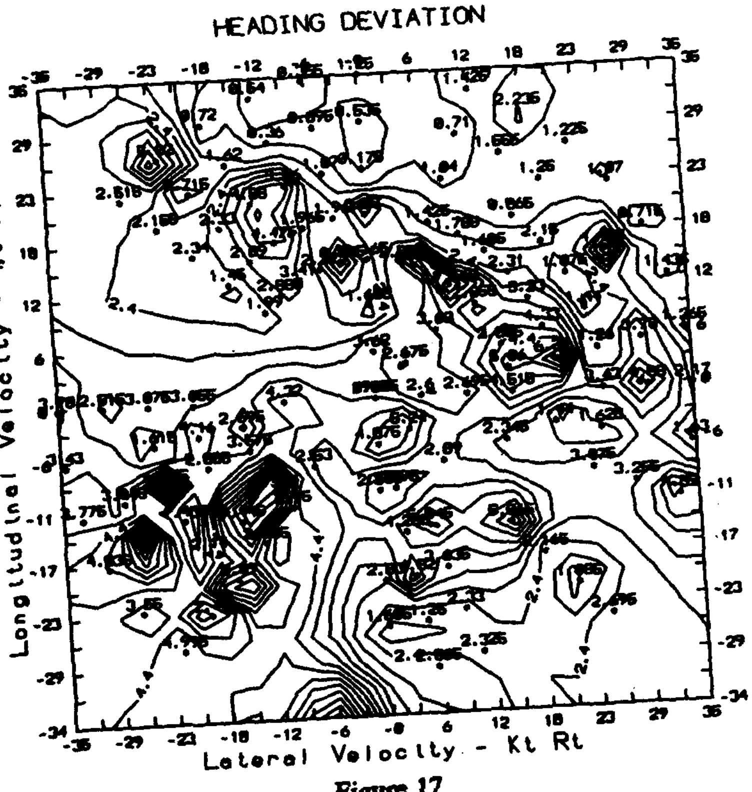
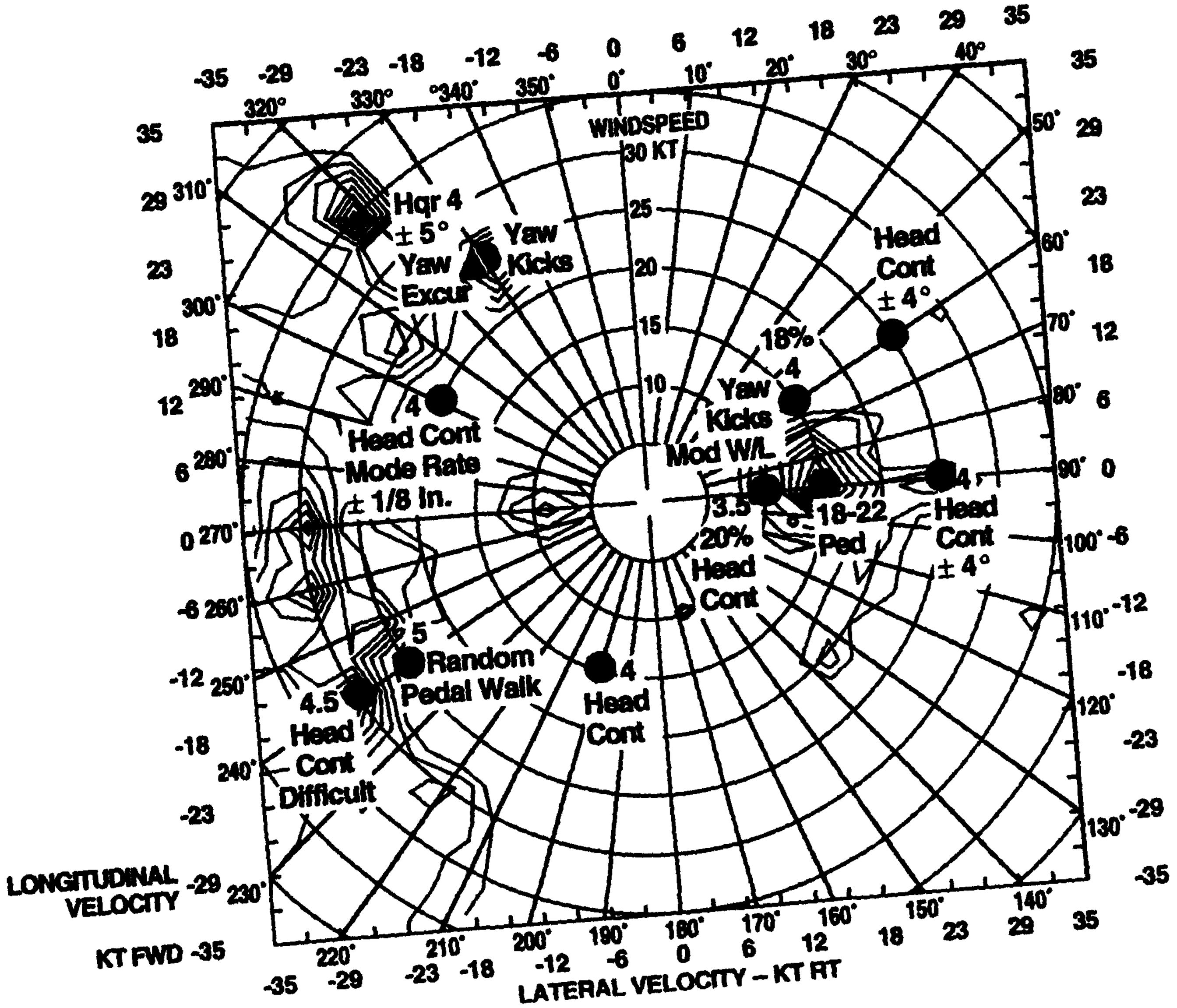


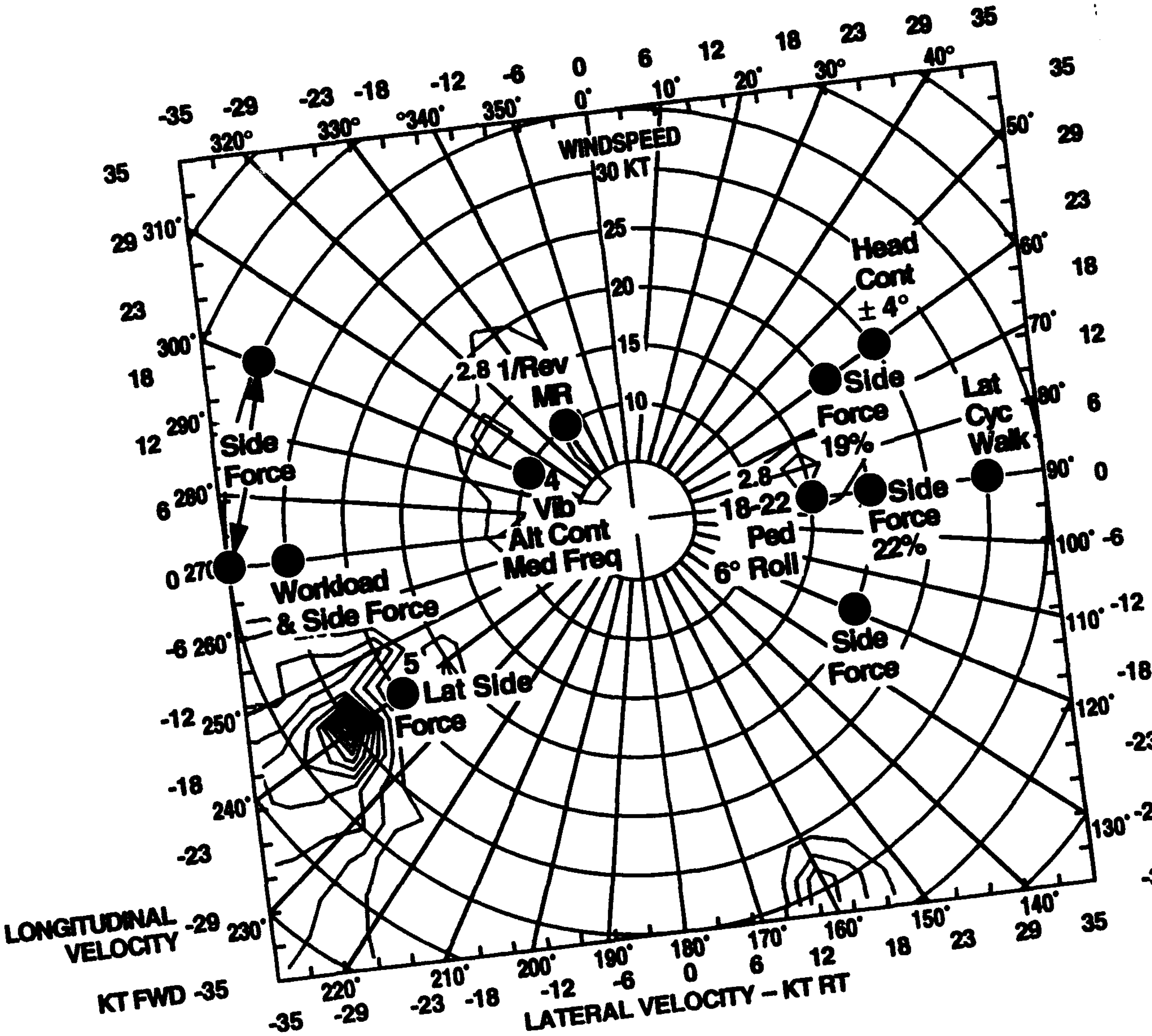
Figure 17
HEADING DEVIATION (TOPOGRAPHIC)



▲ T700/SH-2F (= SH-2G) DI Feasibility

● SH-2F 12,800/173

Figure 18
PEDAL WORKLOAD AND HQR'S
(> ±5% PEDAL)



▲ T700/SH-2F (= SH-2G)
DI Feasibility

● SH-2F 12,800/173

Figure 19
LATERAL WORKLOAD AND HQR'S
(> ±2.7% LAT CYCLIC)

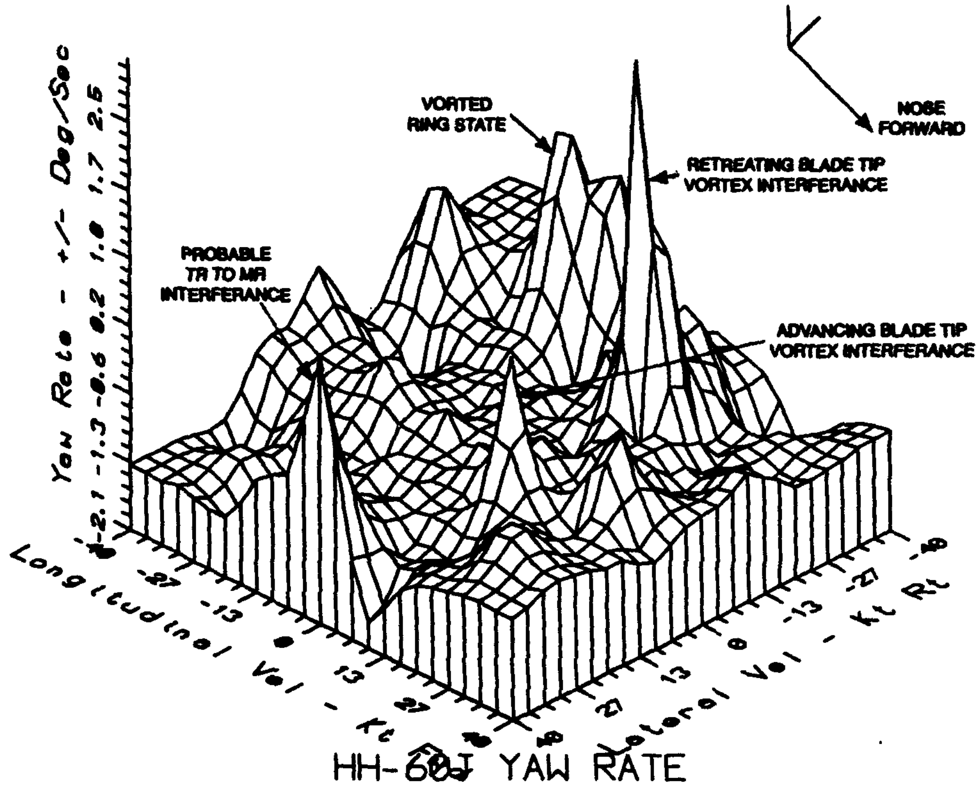


Figure 20
HH-60J YAW RATE (SURFACE)

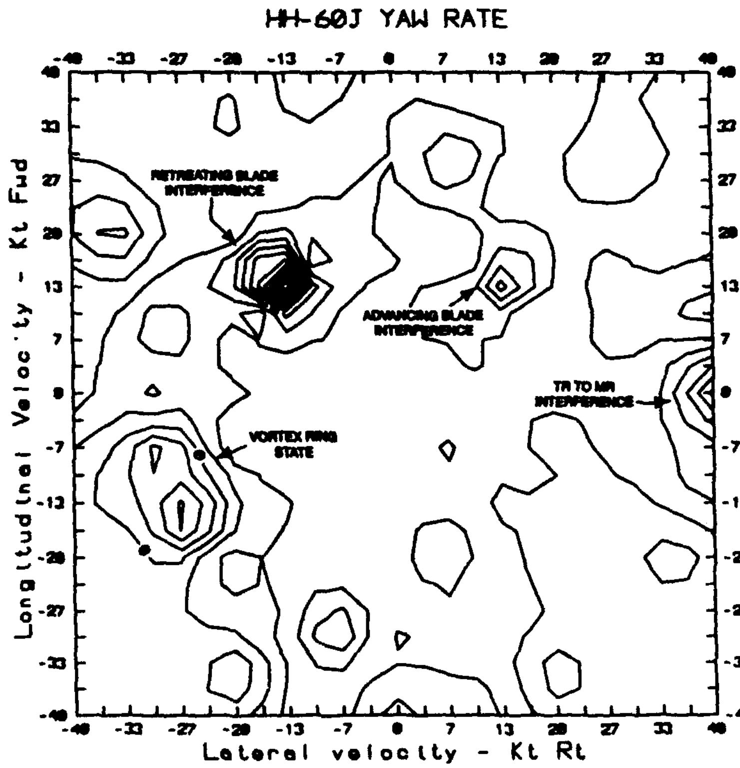


Figure 21
HH-60J YAW RATE (TOPOGRAPHIC)

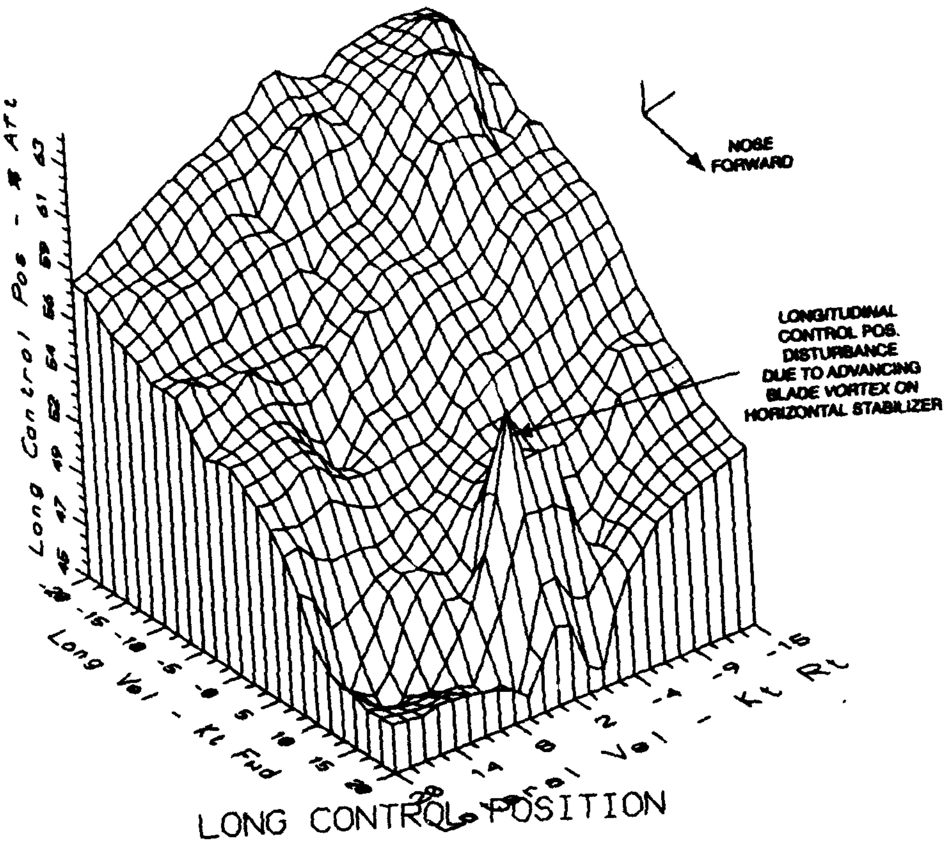


Figure 22
LONGITUDINAL CONTROL POSITION

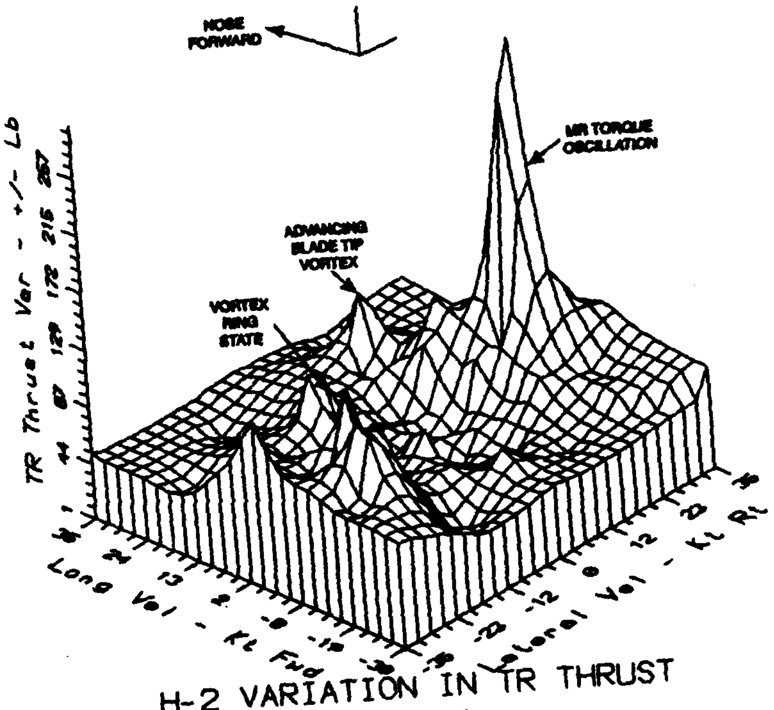


Figure 23
H-2 VARIATION IN TR THRUST

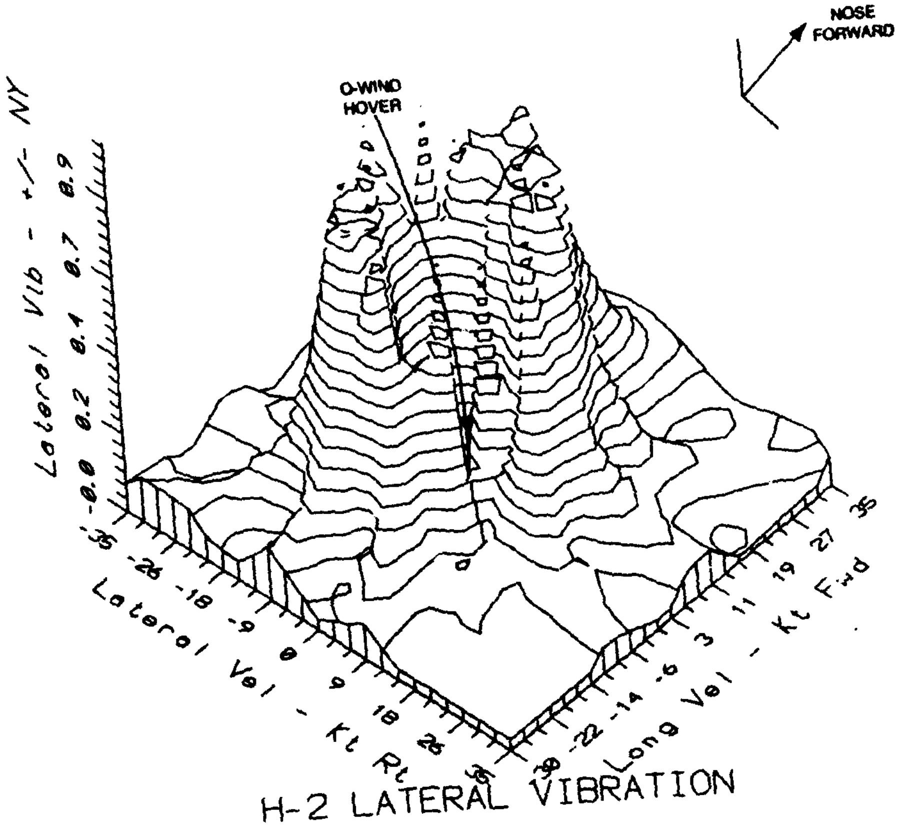


Figure 24
H-2 LATERAL VIBRATION

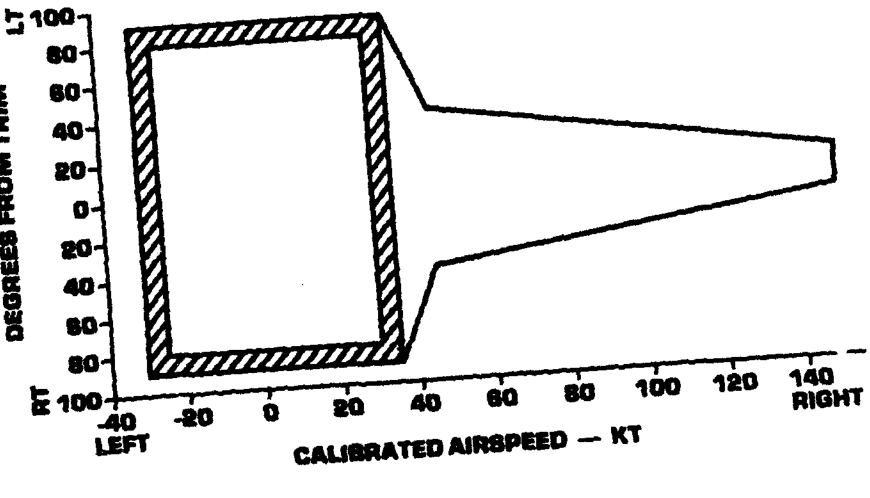


Figure 25
SIDESLIP ANGLE LIMITATION

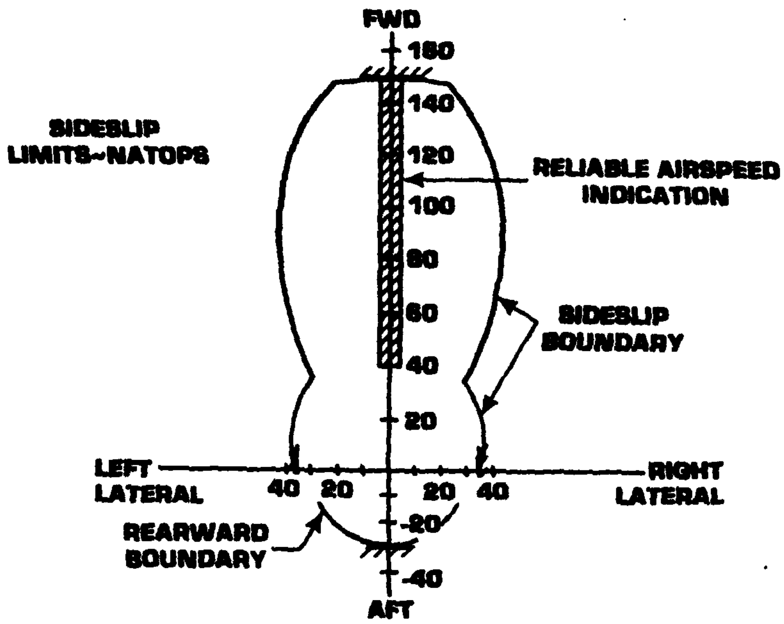


Figure 26
X-Y VELOCITY LIMITS (CARTESIAN)

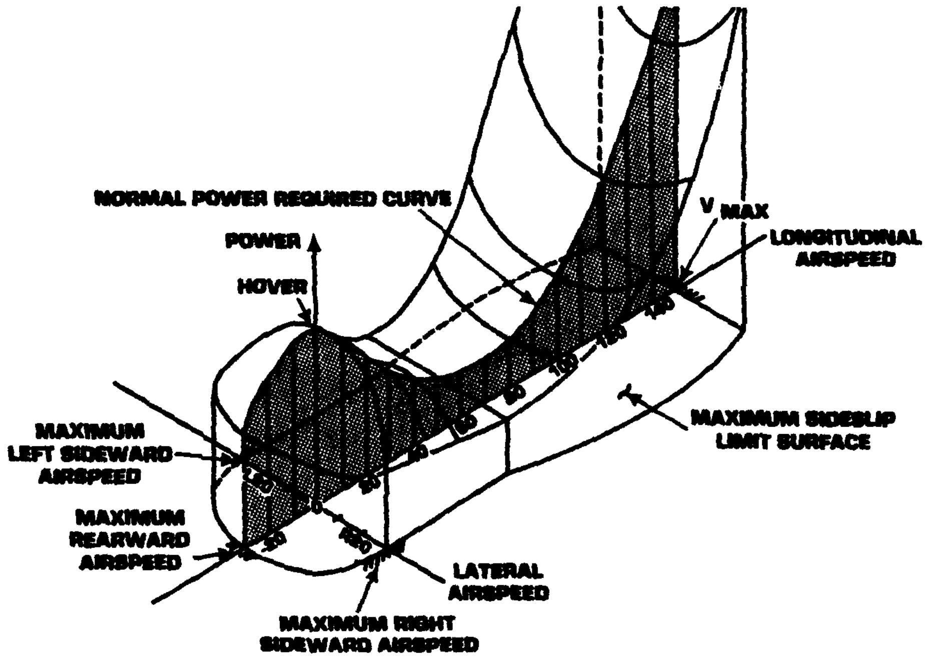


Figure 27
3-D HELICOPTER PERFORMANCE - SURFACE PLOT
(POWER REQUIRED)

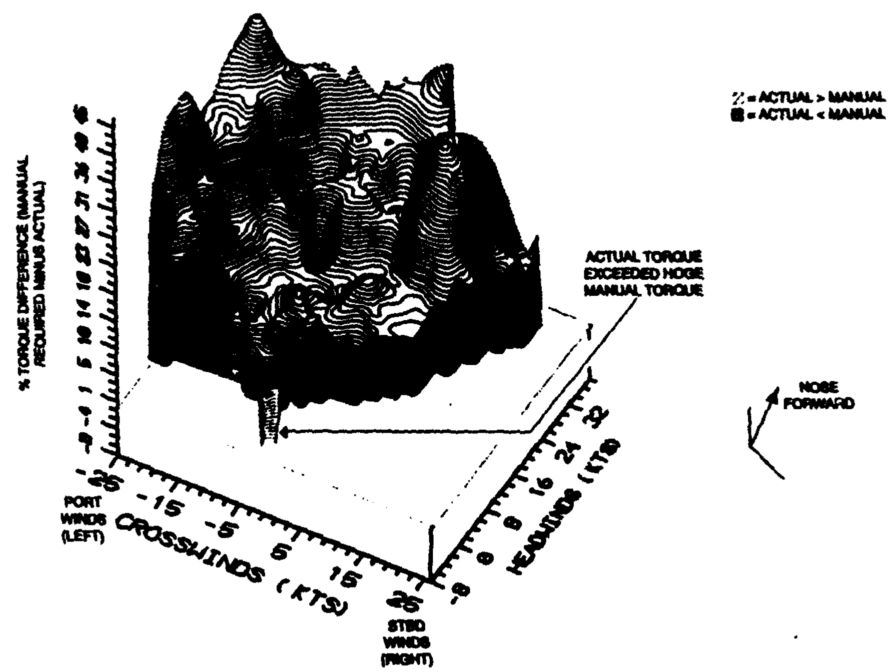


Figure 28
SH-60F NATOPS FLIGHT MANUAL PREDICTED HOGE/SHIPBOARD TEST TORQUE DIFFERENCE

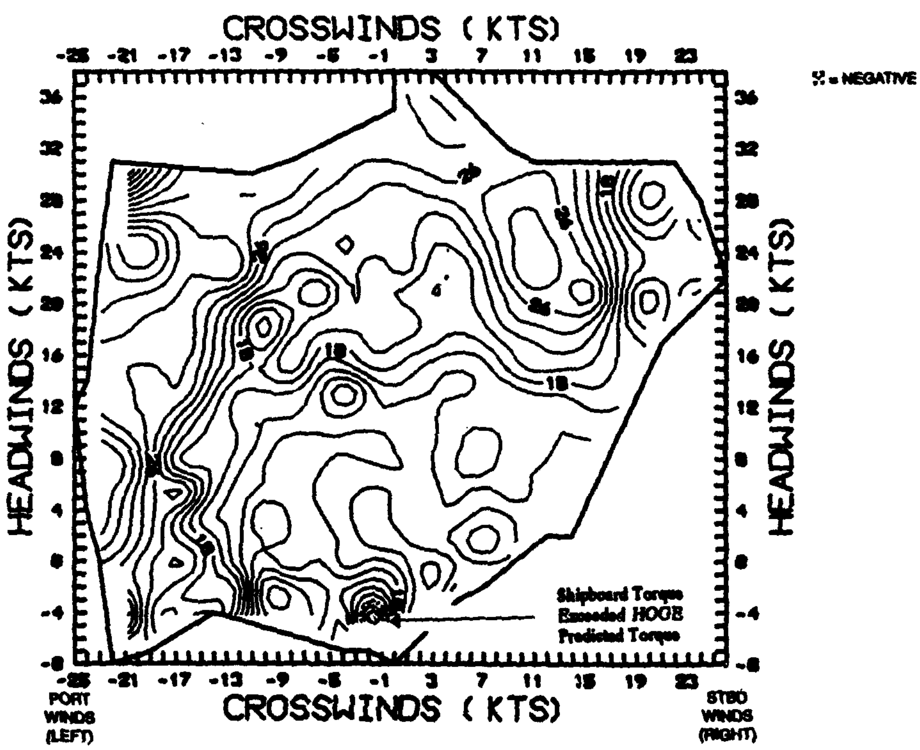


Figure 29
SURFACE PLOT OF SH-60F NATOPS FLIGHT MANUAL PREDICTED HOGE/SHIPBOARD TEST TORQUE DIFFERENCE

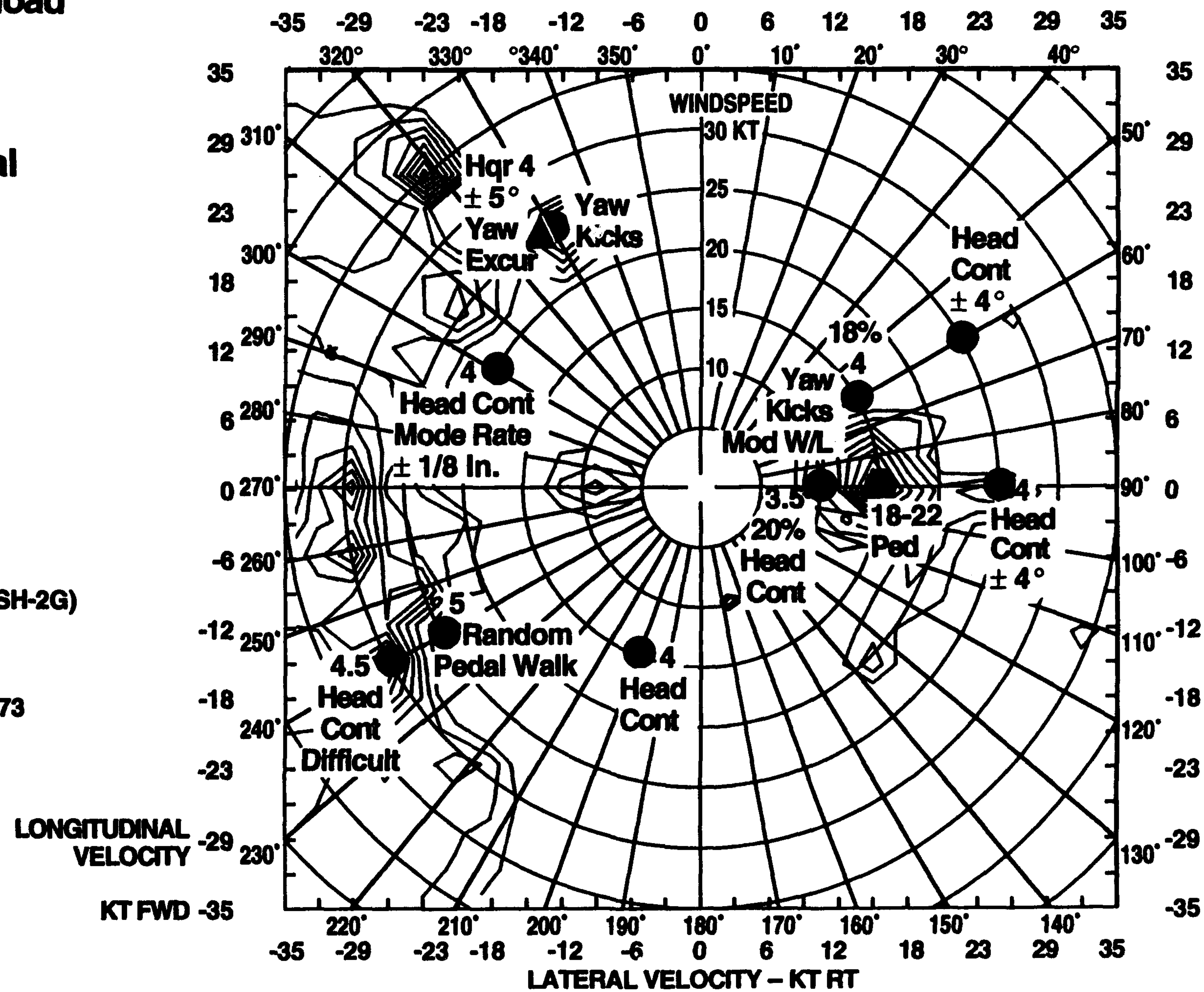
Pedal Workload

and Hqr's

> ±5% Pedal

▲ T700/SH-2F (= SH-2G) DI Feasibility

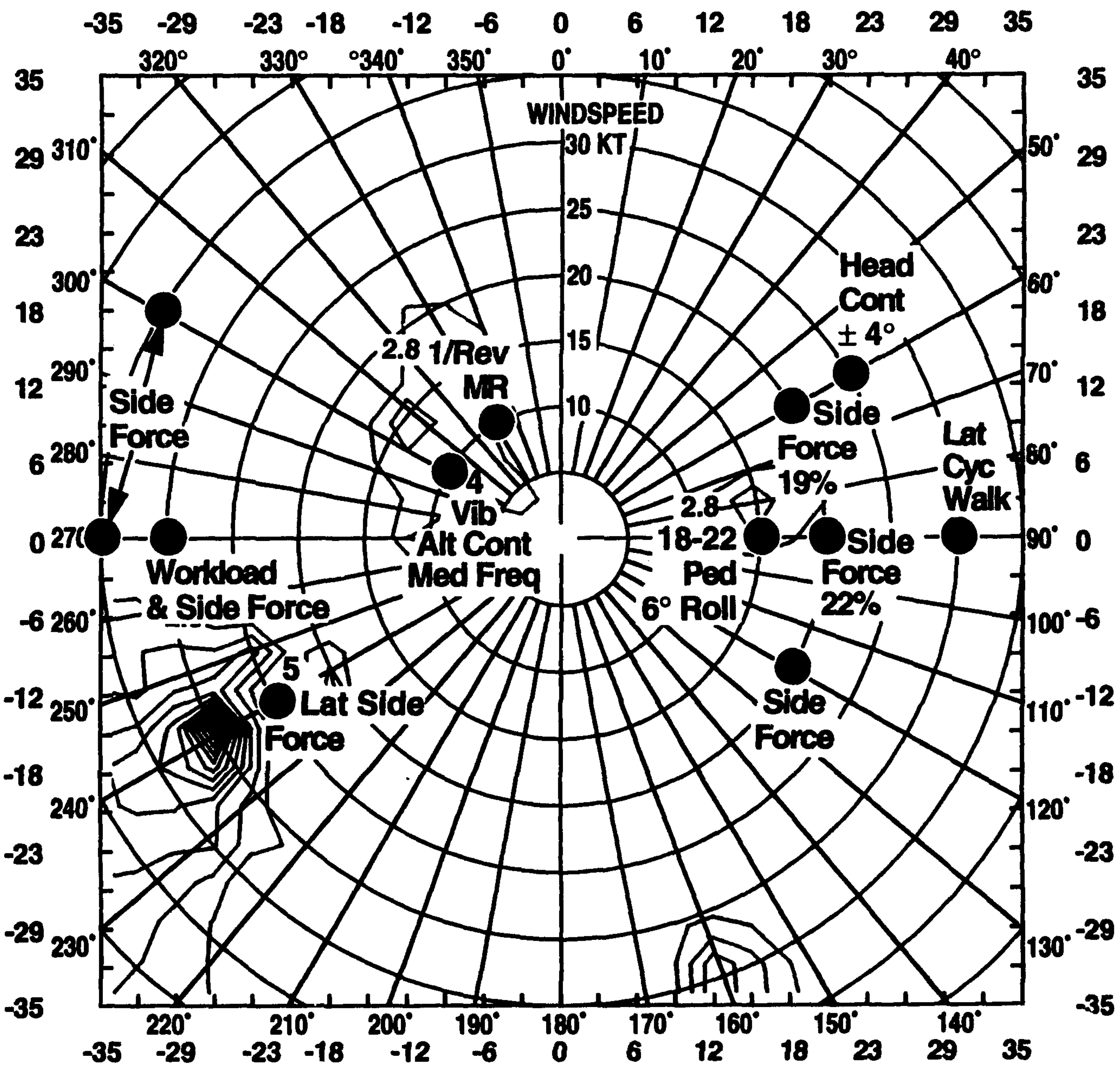
● SH-2F 12,800/173



Lateral Workload

and Hqr's

> ±2.7% Lat Cyclic



▲ T700/SH-2F (= SH-2G)
DI Feasibility

● SH-2F 12,800/173